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Mechanical behaviour of self-compacting concrete made with recovery filler from hot-mix asphalt plants

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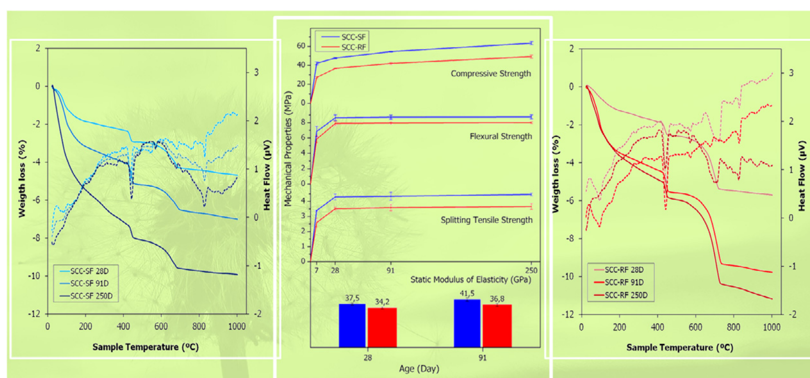
HIGHLIGHTS

- A comparative study of two types of SCC was carried out.
- The aging mechanism of the SCC mixes (SCC-SF and SCC-RF) was different.
- Pozzolanic reactions occurred during curing of the SCC-SF.
- Shrinkage in the SCC-RF was lower because of the larger particle size.
- Recovery filler from hot mix asphalt plants is adequate to produce SCC.

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of this paper is to assess the feasibility of the use of a fine grain waste generated in hot-mix asphalt plants (HMA), namely recovery filler (RF), as filler materials in self-compacting concrete (SCC) production. A comparative study of two types of SCC was performed. The first concrete type was made incorporating recovery filler (SCC-RF) of a dolomitic nature and the second was made with commercial siliceous filler (SCC-SF), the latter used as reference. Good results of self-compatibility were obtained using RF. The thermogravimetric study showed that in SCC-SF the higher loss weight occurs in the dehydration zone (0–400 °C) and in SCC-RF it occurs in the decarbonation area (550–735 °C). The aging mechanism of both concrete types (SCC-SF and SCC-RF) was different. In the SCC-SF mixes, portlandite undergoes carbonation processes and pozzolanic reactions and in the SCC-RF mixes it only undergoes carbonation processes. The experimental results (splitting tensile strength, flexural strength and static modulus of elasticity) show the validity of using EHE-08, initially proposed for NVC (Normally Vibrated Concrete), in SCC. The ultrasonic pulse velocity values for SCC-SF was greater than for SCC-RF, which can be attributed to compacity and compressive strength. The shrinkage behaviour was better in SCC-RF than SCC-SF, mainly due to the greater particle size of recovery filler (RF), although the SCC-RF mixes showed lower density and mechanical strength than SCC-SF. In short, the SCC manufactured

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with recovery filler from plants manufacturing hot-mix asphalt (HMA) – SCC-RF – is expected to have better features than SCC-SF in relation to shrinkage and early appearance of cracks.

1. Introduction

Concrete is the building material most commonly used, twice more than other materials (wood, steel, plastic or aluminum). Its worldwide production is estimated at 4 tons per person and year [1]. Since it is the material that consumes more natural resources [2], it is not considered environmentally-friendly. For this reason, the concrete industry is constantly evolving, seeking more efficient technologies with high optimization of natural resources. In the 1980s, Self Compacting Concrete was born (SCC), as an evolution of existing technology, and its use has been widespread in recent years in civil engineering, especially in the precasting industry, providing solutions to the different problems presented by ordinary concrete (OC). SCC is characterized by not requiring vibration and compaction, flowing under its own weight, completely filling the mould to be cast, achieving full compaction in the presence of high density reinforcement and homogenizing hardened concrete, all of which translates into benefits such as reduced lead times, production of complex structures, better surface finishes, reduced labour cost, improved job security, and noise and vibration reduction [3].

Nowadays there is a strong line of research related to global resource optimization and waste minimization in the construction field. The application of several wastes as replacement of the different materials involved in the manufacture of SCCs has been studied. Some of this research has dealt with the use of mining waste as fine aggregate and/or filler with good results of self-compactability, excellent surface finish and high mechanical strength [4–6]. Granata [7] investigated SCC with pumice powder instead commercial filler, this research confirmed that pumice powder can be effectively used as filler in SCC. Da Silva and de Brito [8] carried out binary and ternary SCC mixes with fly ash and limestone filler, concluding that the replacement did not significantly affect the behaviour of the SCC studied by comparison with the control SCC with cement only. Ibrahim et al. [9] analysed the potential use of bottom ash as fine aggregate in SCC and observed that, due to the characteristics of this waste, to achieve optimal results regarding self-compactability and mechanical behaviour, three aspects must be taken into account: water/cement ratio, incorporation ratio of bottom ash and curing period. Glass is an indispensable material to man but it generates a lot of waste, creating serious problems for the environment; to contribute to solve this issue Ali et al. [10] proposed its use as fine aggregate because it can successfully be used to produce SCC. Blast furnace slag was investigated by Zhao et al. [11] as mineral admixture for the production of SCC. The differences between the mechanical properties of SCC with and without waste, fresh and at 90 days, were insignificant. Blast furnace slag was investigated by Valcuende et al. [12] as replacement of sand for the production of SCC; at early ages, SCC showed similar compressive strength to the reference SCC. But, as the age increases, the concrete's compressive strength tends to be higher, due to slag reactivity. Other researchers have used other waste, such as Mishra et al. [13], who replaced the coarse aggregate with rubber chips at a percentage 0–20% and concluded that the resulting SCC is adequate for applications where strength is not needed but durability is important. Hesami et al. [14] replaced sand with tire rubber crumb at 5–15% and it can be stated that it has no considerable negative effect on some of the properties, as the abrasion resistance index. Ghernouti et al. [15] made SCC with plastic bag waste as fibres, obtaining a positive effect on mechanical behaviour, especially in splitting tensile strength. Oerkan et al. [16] made SCC with plastic waste from municipal waste as fibres, obtaining a correct mechanical behaviour and less shrinkage. Mohammadhosseini et al. [17] studied the influence of palm oil fuel ash on SCC; the results revealed an acceptable range in terms the workability and an excellent compressive strength for 30% replacement of ash by cement. Ranjbar et al. [18] also studied the influence of palm oil fuel ash on SCC; the results revealed great potential to be used as a replacement of Portland cement in self-compacting concrete preserving fresh, mechanical and durability properties within an acceptable range.

The aim of this paper is the assessment of the feasibility of the fine grain waste, generated in the drying and heating process of aggregates in hot-mix asphalt (HMA) manufacturing plants, as a construction material. This powder named "recovery filler" (RF) drops from the rotating drum together with the combustion gases and water vapour and is retained by baghouse filters to prevent its dispersal into the atmosphere. Sometimes it is partially stored in silos for use as recovery filler in the manufacturing of new HMA used as base layer in road pavements. This use represents around 3–4%. The greater part of RF is sent to dumping grounds or, if the plants have their own quarry, is deposited as illegal filling, resulting in environmental problems and health risks. This type of waste is in direct contact with fuel oil burners and often cannot be classified as inert in accordance with the European Council Decision 2003/33/EC. The amount of RF generated is estimated at 4% by weight of HMA produced, which depends on the nature of the aggregate and the amount of HMA. World production exceeds 700 million tons of asphalt mixtures (2014), of which 14.5 million tons were produced in Spain [19]. This waste can be recycled and reduce the consumption of natural resources, save energy, reduce materials costs and waste dumping. The use of this waste as construction material has not been discussed in depth [20] and, given the high volume of fine materials required in SCCs, it would be useful to analyse its behaviour in the manufacture of SCCs.

In this paper a comparative study of two types of SCC was carried out. In the first one, a recovery filler (RF) of dolomitic nature was used and, in the second, a commercial siliceous filler (SF) was used as reference. The amount of filler used in both cases was the same. To determine the behaviour of these two types of SCC, fresh properties such as flowability, blocking resistance and resistance to segregation were analysed to know the properties of self-compatibility. An extensive research of hardened SCC was conducted to correlate the microstructural properties with the long-term mechanical behaviour. Finally the early-age shrinkage was determined.

2. Experimental plan

2.1. Materials characterization

The crushed rock aggregates were supplied by Aggregates Gallardo S.L, "La Coronada" (Badajoz, Spain): gravel 4/16 (G), coarse sand 0/4 (S1) and fine sand 0/2 (S2). The particle size distribution of the aggregates is shown in Fig. 1. According to the results of the geometric-physical-chemical characterization (Table 1), the aggregates are suitable for concrete production according to the Spanish Instruction of Structural Concrete (EHE-08) [21]. XRD patterns